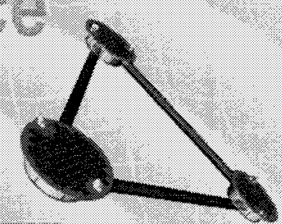
LISA Instrument Performance



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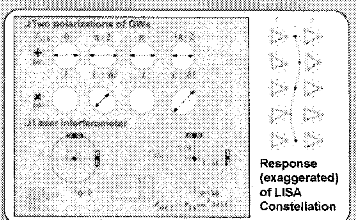
Abstract

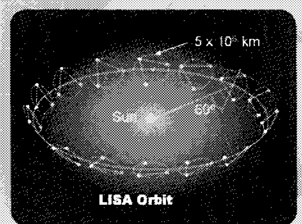
LISA is designed to observe gravitational waves in the frequency band from 10^{-1} to 10^{-4} Hz, where a rich spectrum of sources is expected. The measurements must be made from space to avoid the large motions of the earth that prevent the current generation of detectors (e.g. LIGO) from operating at these frequencies. The technology and expected performance behind this measurement capability will be reviewed with an emphasis on the interferometric measurement system, including recent laboratory results showing a novel tunable frequency-stabilized laser.

Overview of the Mission

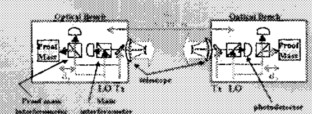
The LISA mission studies gravitational waves by detecting the strain they produce with a laser interferometer that measures the distance between pairs of freely floating proof masses arranged in a 5×10^6 km equilateral triangle constellation that orbits the sun 20° behind Earth's orbit. The plane of the triangle is angled at 60° with respect to the ecliptic. Each of the three spacecraft are in independent orbit around the sun, so no station-keeping is required to keep the constellation together. The proof masses are isolated from disturbances by using drag-free satellite technology that keeps a spacecraft centered around the proof mass as it moves.



Direct GW detectors like LISA measure the changes in distance between inertial reference particles caused by passing GWs.



The LISA constellation is placed in a heliocentric orbit at 1 AU

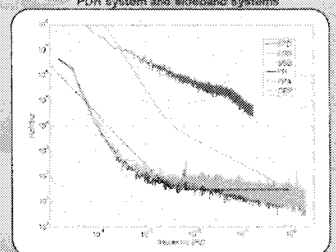


LISA uses a 3-part distance measurement to monitor the distance between proof masses on each SC.

Short arm $(d_1 + d_2)$ + long arm $(d_{12}) = d_{ps}$

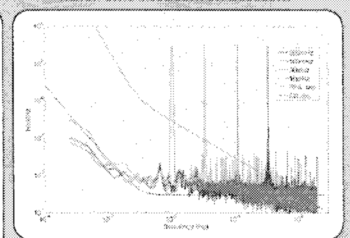
Results: Same performance as without tunability

Stability of beat note between standard PDH system and sideband systems



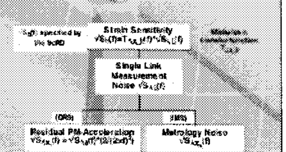
- All schemes work at ~ same level
- Performance matches current performance of standard system (not yet limited by sideband sensing)
- All schemes meet Current Baseline Requirement for pre-stab + arm-locking

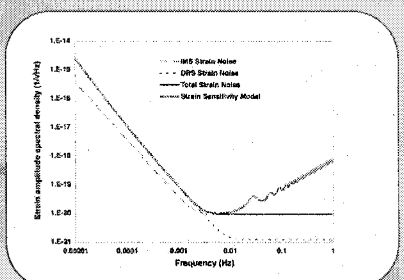
Narrow-band modulation demonstration



- Narrow-band modulation does not raise broad-band noise floor

Noise Model/Requirements Flowdown





Disturbance Reductions System (DRS) High Level Error Budget

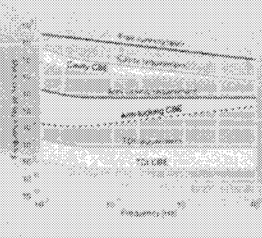
[illegible]

Interferometric Measurement System (IMS) High Level Error Budget

[illegible]

Mitigating Laser Frequency Noise

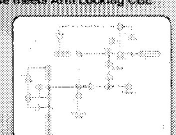
- Mismatched arm-lengths allow frequency noise of the LISA lasers to enter into GW measurement signal
- Achieving design sensitivity requires suppressing laser frequency noise by ~13-14 orders of magnitude
- Baseline LISA design is a "divide & conquer" approach
  - Pre-Stabilization: stabilize to local optical cavity on each SC
  - Arm-Locking: enhanced stabilization using LISA arm as reference
  - TDI: common-mode rejection through specific combinations of individual phase measurements
- Utilizing both Arm-Locking & Pre-stabilization requires a pre-stabilization system that can be tuned



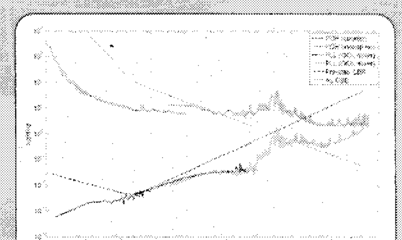
The LISA frequency noise mitigation plan contains three techniques to achieve 13+ orders of magnitude noise rejection

Phase Locking with Pre-stabilization

- Demonstration of tunable pre-stabilization as an actuator in an external loop
- PLL has unity gain frequency (UGF) of ~10kHz
- PLL UGF limited by UGF of PDH loop, not actuator.
- In-band noise meets Arm Locking CBE

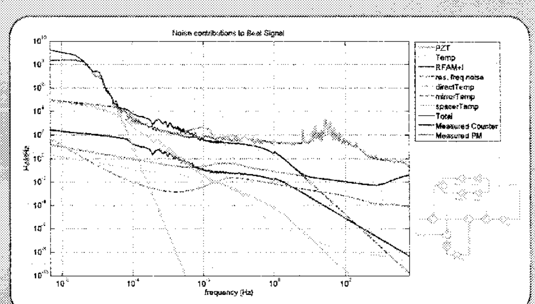


Pre-stabilized phase lock loop



Preliminary results showing pre-stabilized noise level (red, magenta) and pre-stabilized + phase-locked noise level (blue, cyan)

Noise Model



- Uses calculated and measured loop transfer functions with noise injected at different points
- Includes
  - Electrical circuit noise (non-fundamental) including RF-AM at the modulation frequency
  - Temperature effects including direct cavity length changes and mirror heating through intensity noise and absorption
  - Optical noise, including residual frequency noise

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